(12) UK Patent Application (19) GB (11) 2 184 859 (13) A

(43) Application published 1 Jul 1987

(54) Fibre optic devices

(57) A fibre-optic device which can be used as an attenuator or a sensor includes a biconical taper 2 which is surrounded by a medium having a varying refractive index so that light transmission through the core can be used as a sensor in measuring temperature, refractive index. When used as a tuneable attenuator electrodes 4, 5 are mounted in contact with the medium so that it can be heated to vary transmissivity through the core. The medium may be silicone oil, or an electrically-controlled material such as KDP or a liquid crystal. The sensor provides compensation against external variations by propagating two wavelengths and dividing the respective output powers.

Fig.5.

GB 2 184 859 A

Fig.1.

a

b

c

d

Fig.3.

TRANSMITTED POWER (dB)

TAPERING TIME

Fig.6.

TRANSMITTED POWER (dB)

AT $\lambda = \lambda_2$,
COMPENSATION WAVELENGTH

← REFRACTIVE INDEX →

2184859

Fig. 2.

3b

TAPER LENGTH

20 mm

20dB

Fig. 4.

TRANSMITTED POWER (dB)

REFRACTIVE INDEX

A
29°C.
-14.3 dB

B
55°C.
-32.5dB

C
26.8°C.
-42.8dB

Fig.5.

Fig.7.

H DEC86   29058

2184859

Fig. 8.

POWER (dB)

-17.8

-46.0

0

5.42

TAPER LENGTH (mm)

Fig. 9.

POWER (dB)

-20.1

-45.4

1.4432

1.4407

1.4335

REFRACTIVE INDEX
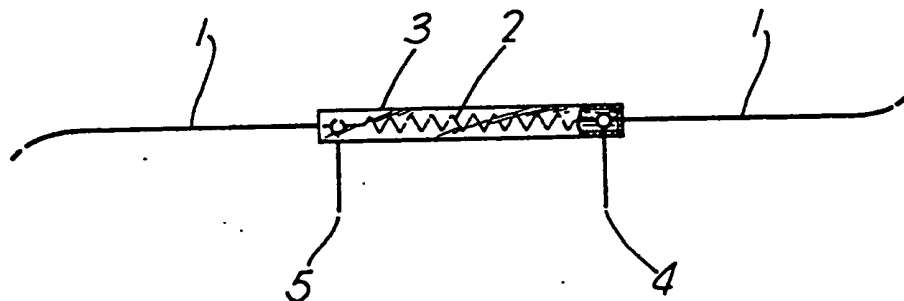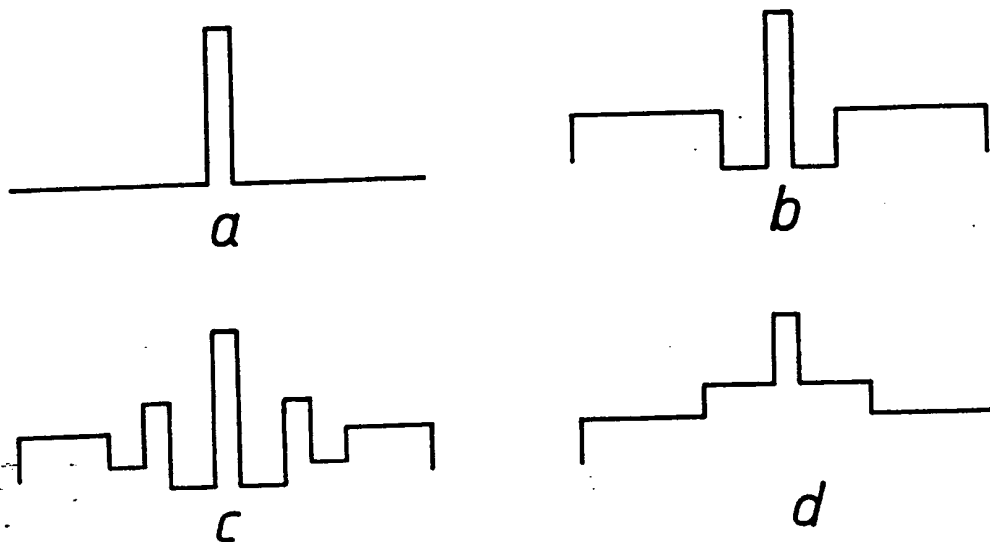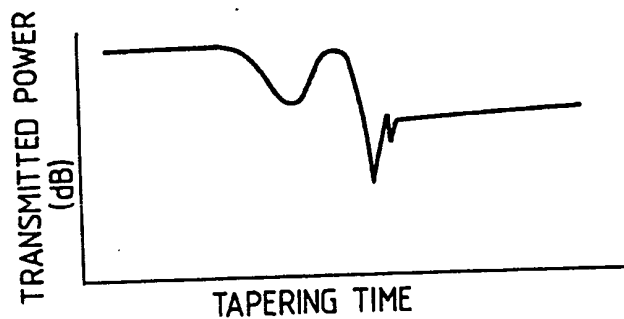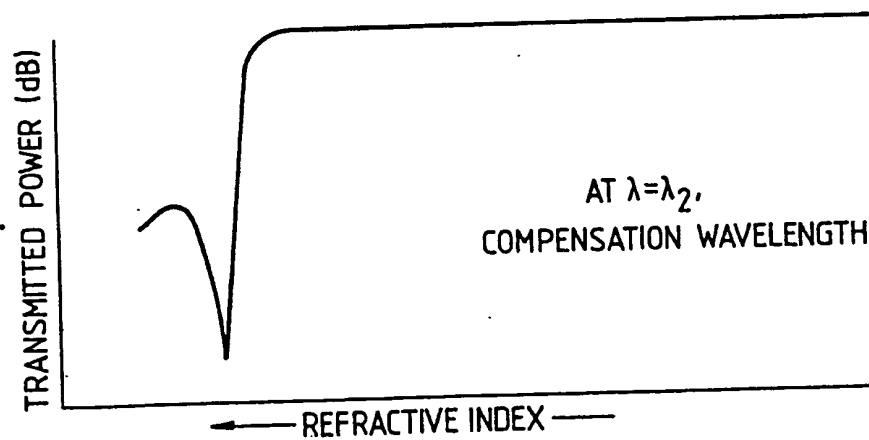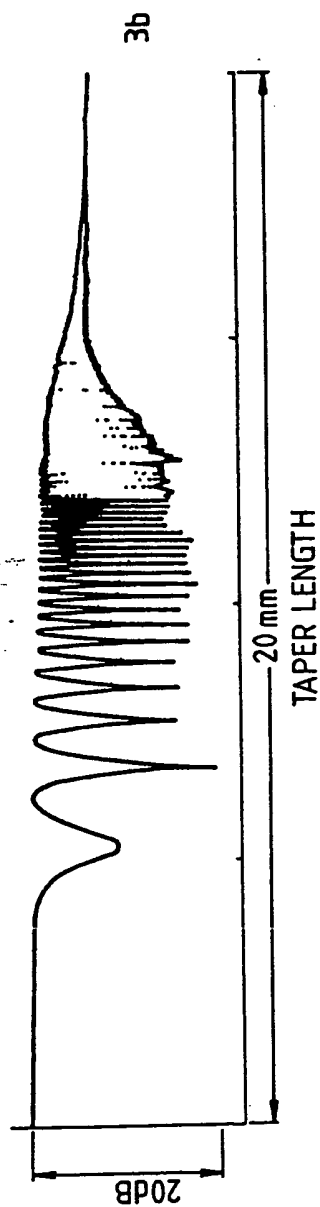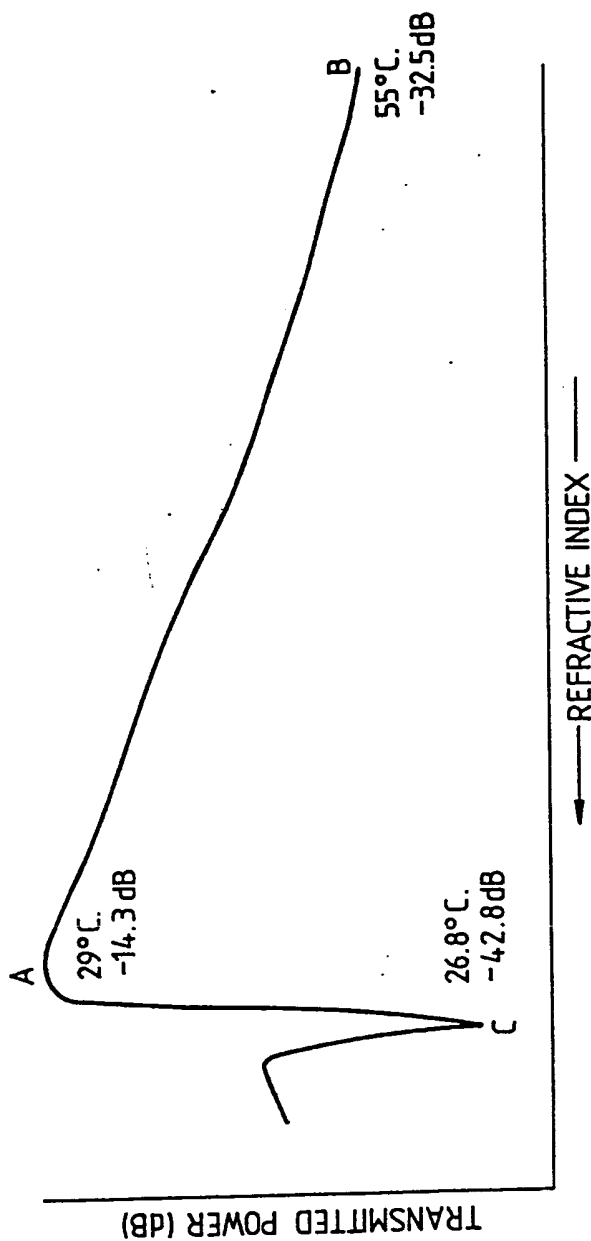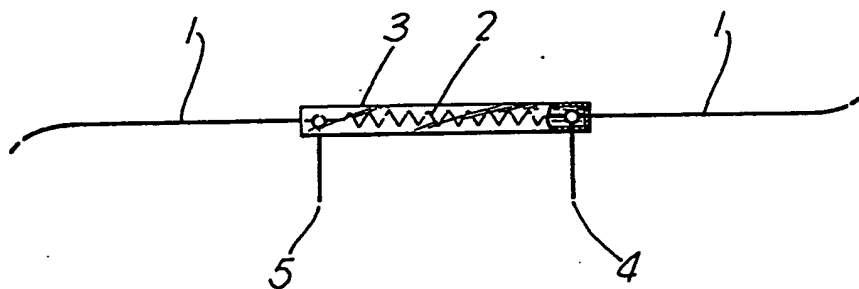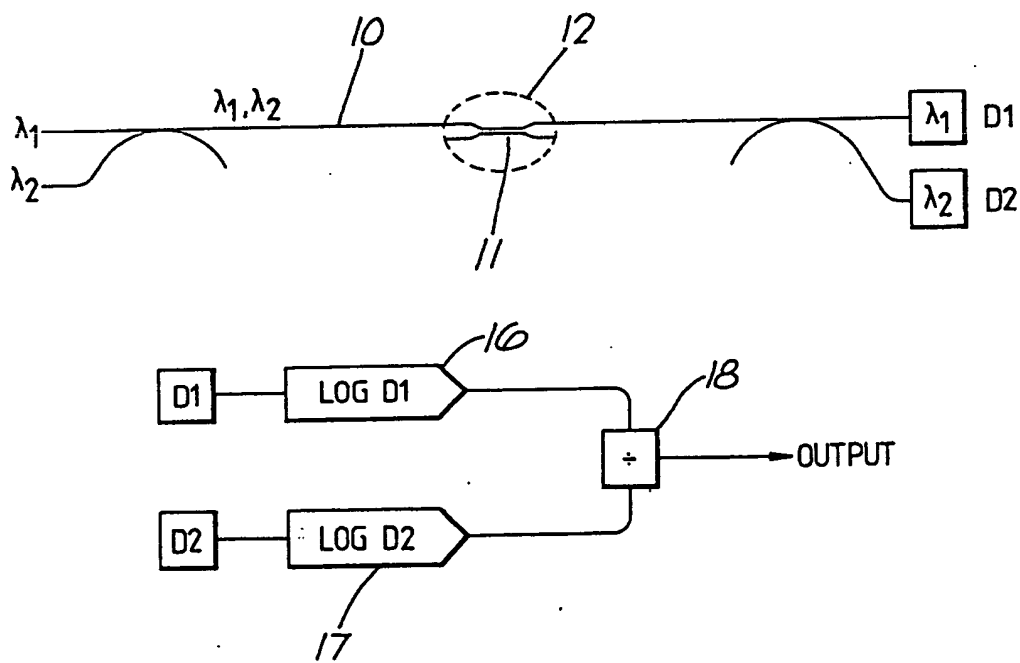
Fig. 10.

Fig. 11.

SPECIFICATION

Fibre optic devices

5 The present invention concerns optical fibre
devices. It has been discovered that optical
fibre couplers can be fabricated by imparting a
biconical taper to a monomode optical fibre.
With the aid of such tapering the core HE_{11}

10 mode can couple into the HE_{11} mode of the
tube waveguide, which is formed due to the
cladding, in an efficient manner.
   The present invention has for an object to
utilise optical fibres having such biconical ta-

15 pers to form devices, including sensing de-
vices and tuneable attenuators, which are sim-
ple to manufacture and which incorporate low
cost electronics.
   Accordingly from one aspect the present in-

20 vention consists in an optical fibre device
comprising a monomode optical fibre having
an optical coupler fabricated therein in the
form of a biconical tapered portion, means for
modifying the refractive index of a medium

25 surrounding the tapered portion so that for a
specified wavelength travelling along the fibre
the power transmitted will vary in accordance
with variation in the refractive index of the
medium, and means for detecting light

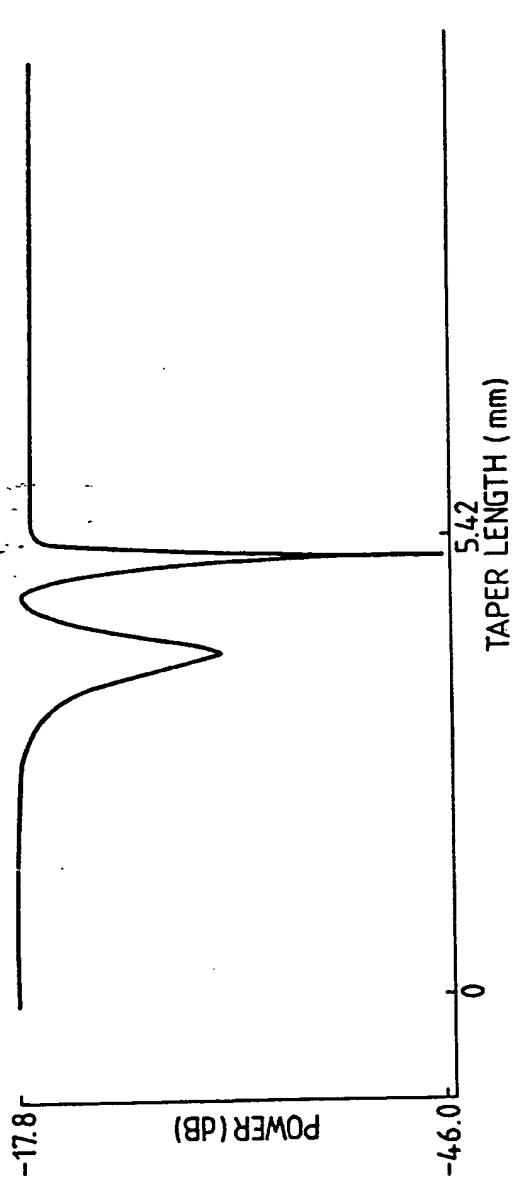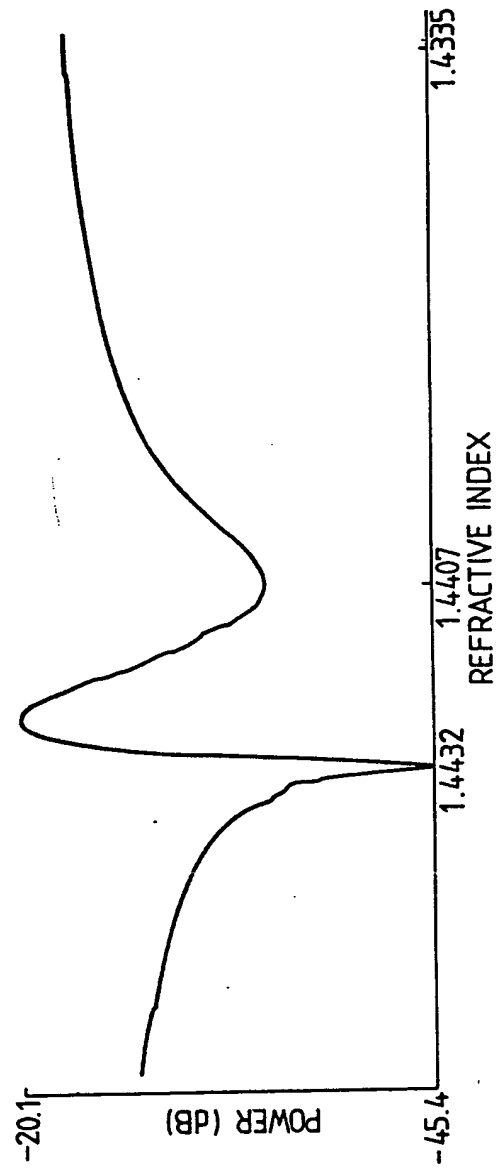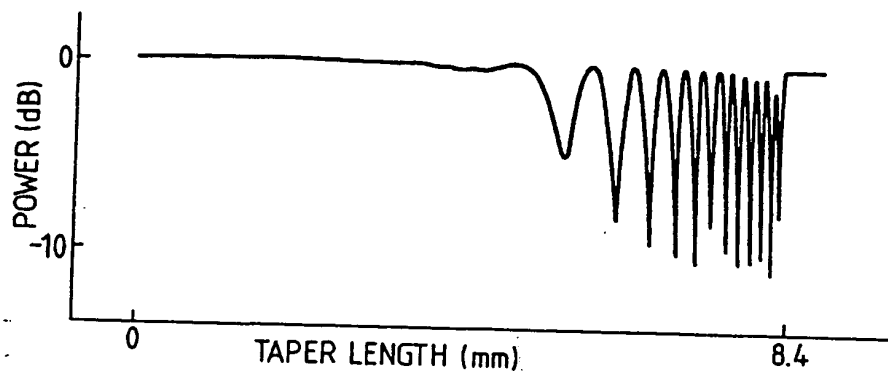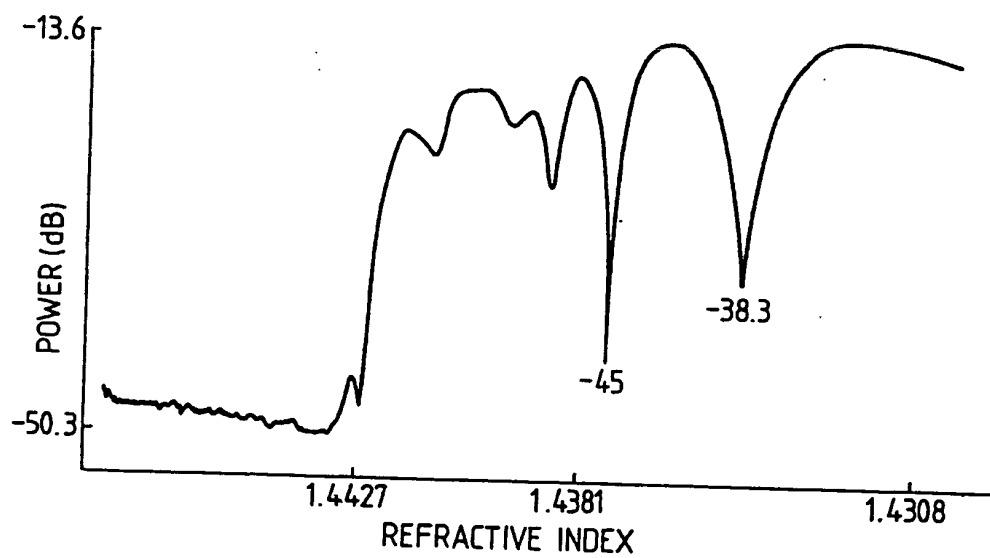30 transmitted by the core of the optical fibre.
   In order that the present invention may be
more readily understood, two embodiments of
devices constructed in accordance with the in-
vention will now be described by way of

35 example and with reference to the accom-
panying drawings, in which:
   Figure 1 shows various refractive index pro-
files taken across the diameter of optical
fibres suitable for use in sensors according to

40 the present invention,
   Figure 2 is a plot of transmitted power
against extension of an optical fibre during the
process of producing a biconical taper in the
fibre,

45   Figure 3 is a plot similar to Fig. 2 showing
the effect of stopping extension at a selected
point,
   Figure 4 is a plot showing the refractive
index response of the taper, the refractive in-

50 dex varying in response to temperature varia-
tions,
   Figure 5 is a diagram showing how a tem-
perature-linked refractive index variation can
be applied to a tapered fibre to make a fusea-

55 ble attenuator,
   Figure 6 is a plot of the refractive index
response of a tapered fibre at a second wave-
length,
   Figure 7 is a diagram of a sensing device,

60 and.
   Figures 8 to 10 are vaious plots again
showing the responses obtained to varying
degrees of taper and surrounding refractive in-
dices.

65   Referring now to the drawings, the refrac-

tive index profiles shown in Fig. 1 show some
of the types of single mode optical fibres
which can be utilised in carrying out the pre-
sent invention. The profiles a, b, c, d, e and f

70 respectively relate to Matched, Depressed,
Quadruple Clad, Segmented Core and Raised
Cladding optical fibres.
   All these types of fibre can be formed into
coaxial couplers by the process described in

75 our co-pending U.K. Application No. 8519086
entitled "Coaxial Couplers". In this process
laser light is launched into one end of an opti-
cal fibre and the transmitted power detected
at the other end. Whilst the light is being

80 transmitted a portion of the fibre is simultane-
ously heated and elongated, generating a bi-
conical taper in the fibre. The light guided in
the core of the single mode fibre is directed
into the tapered section. The tapering being

85 applied causes the tapered portion to become
a multi-mode section, and interference of the
local HE_{11} and HE_{12} modes causes power
transfer along the taper. If the taper length is
such that for the particular taper shape power

90 emerges at the taper end in the core of the
fibre, then the light will be transmitted. If,
however, it emerges in the cladding it will be
lost. This can be seen from the plot shown in
Fig. 2 which consists of power oscillations

95 induced by the tapering process. Fig. 2 shows
the result if the taper is elongated until it
breaks. However, the tapering process can be
stopped at will. Fig. 3 shows the power
transmission response when extension of a

100 fibre portion to produce a biconical taper has
been stopped just after $1\frac{1}{2}$ detected power
oscillations.
   A tapered optical coupler produced by this
procedure can be incorporated in a range of

105 sensing devices by utilising the refractive in-
dex response of the tapers. Then if the ta-
pered portion is immersed in a liquid such as
silicone oil, which has a higher refractive index
than silica, and the liquid is heated so that its

110 refractive index varies the response of the ta-
per to light of a particular wavelength will
vary. This variation is shown in the plot of
Fig. 4.
   From this plot it can be seen that there is

115 maximum power transmission at point A. This
is at a temperature of 29°C. At higher temper-
atures the power throughput decreases almost
linearly as temperature rises. Thus point B
shows power transmission at 55°C. The sec-

120 tion A–B of the plot can be used to provide a
sensor with relatively low sensitivity and good
dynamic range in which a change of refractive
index of the order of 10^{-2} corresponds to a
change in temperature of approximately 30°C,

125 and requiring a detection sensitivity range of
~20 dB, These figures provide the basis for
an intensity sensor for the measurement of
temperature, refractive index, acoustic, biologi-
cal and other sensors which directly or indi-

130 rectly use this refractive index and intensity

relation.

However use of such a device as an inten-
sity sensor raises a number of problems. For
example, external variations such as bending,
5 microbending, etc. could affect the intensity
transmitted. To overcome these drawbacks
some form of compensation is required. This
can be achieved by a dual wavelength
transmission. Fig. 6 is a plot of the refractive
10 index response of the same taper at a second
wavelength when subjected to the same
changes in refractive index as caused the plot
of Fig. 4. It will be seen here that the linear
slope A–B of Fig. 4 has been replaced by a
15 substantially constant plateau. It is the ability
of a single fibre to give two such separate
results which enables a compensating factor
to be built in to a sensor.

Such a compensated sensor is shown in
20 Fig. 7. Laser light at two differing wavelengths
λ_1, λ_2 is launched down a single monomode
optical fibre 10 which has a biconical taper
imparted to it at 11 and which is surrounded
by a sensor area generally indicated at 12.
25 This sensor area could, for example, be a
capillary tube filled with silicone oil as in the
embodiment shown in Fig. 5. In any case it
will be such that the tapered portion 11 will
give power transmission plots of the kind
30 shown in Figs. 4 and 6 in response to
changes in the refractive index of the sur-
rounding sensor area, and in response to light
of wavelengths λ_1 and λ_2 respectively.

. The two wavelengths can be launched into
35 the fibre by means of a coupler. It will be
appreciated that with a device of the charac-
teristics just described measurement will only
occur at wavelength λ_1. At the output end of
fibre 10 the two wavelengths λ_1 and λ_2 are
40 separated, for example, by another coupler.
and the power transmitted by each of the
wavelengths detected by detectors D1 and
D2. The outputs of the detectors are con-
nected to logarithmic amplifiers 16, 17 the
45 outputs of which are divided by a divider 18.
The result is a linear output as a function of
temperature, or of refractive index of the sub-
stance surrounding the biconical taper. Thus
temperature, refractive index and acoustic sen-
50 sors can be made with this arrangement.

Such sensors would be simple to make with
low cost electronics.

Another application involving this relation-
ship, and in particular part A–B of the refrac-
55 tive index response is that of a tuneable at-
tenuator. By changing the refractive index sur-
rounding the taper the throughput attenuation
is changed linearly in dB. Thus Fig. 5 shows a
tuneable attenuator. A monomode optical fibre
60 1 has a biconical taper fabricated in it in the
region generally indicated at 2. This region is
housed in a capillary glass tube 3 filled with a
liquid such as silicone oil the refractive index
of which varies with ⬤erature over the re-
65 quired ranges. The e⬤f capillary 3 are

sealed with UV-cured epoxy resin. The tube is
coated with resistive material and provided
with electrodes 4 and 5. The application of a
voltage across the electrodes causes the heat
70 released to heat the liquid and lower its re-
fractive index, hence varying the transmission
through the fibre 1. In this manner a tuneabil-
ity of >30 dB can be achieved.

Referring again to the plot of Fig. 4, it can
75 be seen that there is maximum power
transmission at point A. Thus an optical mo-
dulator can be constructed using this fact. To
manufacture an optical moduator a monomode
fibre is surrounded with a material having a
80 refractive index which has a value selected to
provide maximum power transmission. By
shifting refractive index of the surrounding ma-
terial higher (to the left of Fig. 4) the
transmission power is rapidly reduced to a
85 minimum, a loss of approximately 30 dB.

Variations are possible on this basic con-
cept. Fig. 4 shows a plow which has been
derived using a tapered biconical fibre the
elongation of which has been stopped after
90 1½ power oscillations. If instead the fabrica-
tions of the taper had been extended to two
complete power oscillations, as shown in Fig.
8, then using this biconiclly tapered fibre to
produce a plot in response to changes of re-
95 fractive index results in the plot of Fig. 9.
Similarly extending the number of oscillations
to 12 produces the equivalent plots of Figs. 7
and 8.

One advantage afforded by the effect of the
100 increased taper as illustrated in Figs. 8 and 9
is that the range of shift required in the refrac-
tive index to produce modulation is narrower.
This is even more apparent when examining
the plots of Figs. 10 and 11 where the effec-
105 tive bandwidth of changes in the refractive in-
dex along the central peak (between power
points −45 and −38.3 dB) is very small.
Here also the refractive index can be varied in
either direction to obtain modulation. This lat-
110 ter arrangement does have a potential disad-
vantage in that very accurate control of tem-
perature may be required.

Whatever the nature of the tapering various
types of material can be used for the variable
115 refractive index surrounding medium. One pos-
sibility is to use an electro-optic material hav-
ing a sufficiently low refractive index tp match
SiO$_2$ fibres. Alternatively the monomode fibre
could be fabricated from a material having a
120 high enough refractive index to match an elec-
tro-optica crystal such as KDP. The electro-
optic effect could then be used so that the
tapered fibre portion and the crystal together
act as a modulator. If an electro-optic crystal
125 is used as a cladding medium surrounding the
taper it must be grown carefully around the
taper. It is possible to grow single KDP crys-
tals long enough to clad the taper region and
also to enclose the ⬤ating electrodes.
130   As an alternative, ⬤efractive index liquid

crystals are used with SiO_2 guides or with
high refractive index glass fibre tapers.
    For modulators of the kind just described
the necessary change of refractive index of
5 the surrounding medium is $<10^{-3}$.
    Such a modulator would find ready applica-
tion in digital transmission systems. The actual
structure of a modulator employing the prin-
ciples just discussed is similar to that shown
10 in Fig. 5 of the drawings.

CLAIMS
    1. An optical fibre device comprising a mo-
nomode optical fibre having an optical coupler
15 fabricated therein in the form of a biconical
tapered portion, a medium surrounding the bi-
conical tapered portion of the fibre, the refrac-
tive index of the medium being capable of
variation whereby for a specified wavelength
20 travelling along the fibre the power transmis-
sion will vary in accordance with variations of
the refractive index of the medium, and means
for detecting light transmitted by the core of
the fibre.
25   2. A device as claimed in Claim 1, and
including means for launching light at two dif-
ferent wavelengths into said fibre, means for
separating the two wavelengths at the output
end of the fibre, means for detecting the re-
30 spective powers of the transmitted wave-
lengths, and means for generating a compen-
sation factor for one of the wavelengths from
the two detected outputs.
    3. A device as claimed in Claim 1 or Claim
35 2, and including means for varying the refrac-
tive index of the medium.
    4. A device as claimed in Clain 3, wherein
the medium surrounding the fibre is chosen so
that at a specified condition the fibre offers
40 maximum power transmission to a selected
wavelength, and wherein the means for alter-
ing the refractive index of the medium do so
in such a manner that transmission power is
substantially reduced whereby the device can
45 function as a modulator.
    5. A device as claimed in any one of the
preceding claims wherein the medium is a
liquid surrounding the tapered portion.
    6. A device as claimed in Claim 5 wherein
50 the liquid is silicone oil.
    7. A device as claimed in Claim 6 wherein
the means for varying the refractive inded of
the silicone oil comprise heating means.